Buck (A.H.)

AN ESSAY

ON

THE MECHANISM OF THE

OSSICLES OF THE EAR.

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ON THE MECHANISM OF THE OSSICLES OF THE EAR.

By ALBERT H. BUCK, M.D., of New York.*

In 1851 Edward Weber † put forth the doctrine that in the transmission of sound from the external ear to the acoustic nerve the ossicles play the part of a solid angular lever, whose office is to transmit to the fluid of the labyrinth the movements imparted to the *membrana tympani* by waves of sound. According to this doctrine the fluid of the labyrinth is moved only as a whole, and the function of the *membrana tympani secundaria* is simply that of affording a point where the fluid can yield to the pressure made upon it by the base of the Stirrup.

On the other hand, the prevailing doctrine was that the ossicles form a connecting medium through which waves of rarefaction and condensation are transmitted from the *membrana tympani* to the fluid of the labyrinth, and that some waves of sound also reach the labyrinth by way of the *fenestra rotunda*.

* An essay to which a prize was awarded by the Alumni Association of the College of Physicians and Surgeons of New York.

† Berichte über die Verhandlungen der K. Sächs. Gesellschaft der Wissenschaften zu Leipzig. Math. Phys. Classe, 1851.

Between these two views physiologists have been divided in opinion even up to the present time, although the majority perhaps favor the former doctrine.

In the following experiments an attempt has been made to determine by direct observation which view is the correct one. The method employed in the investigation is very simple, and free from the objections to which Politzer's method is liable.* This experimenter attached fine glass rods to different parts of the ossicles and studied their action whilst concentrated waves of sound were being conducted into the external auditory canal. As will be seen farther on, these rods constitute an important disturbing element, both by their weight and elasticity.

I am indebted to Prof. Helmholtz as well for the suggestion of this method, as for his constant assistance throughout the course of the experiments.

Material used, mode of preparing it for observation, and means employed for conducting waves of sound into the external auditory canal.

Specimen.	Age.	Sex.
Nos. 1 and 2.	30.	Male.
No. 3.	20.	Female.
Nos. 4 and 5.	50.	Male.
No. 6.	40.	Male.
No. 7.	20.	Male.
Nos. 8 and 9.	29.	Male.
Nos. 10 and 11.	29.	Male.

In the following experiments eleven human adult temporal bones were used. They were removed from the

* Archiv für Ohrenheilkunde, 1864.

bodies as soon as possible after death, and preserved in a very weak solution of spiritus vini.

A portion of the cartilaginous external auditory canal was left attached to each temporal bone, sufficient to admit of the introduction of a suitable sound-conducting tube. The roof of the drum was then carefully chiselled away until a good view could be obtained of the greater part of the hammer and anvil, and of the head of the stirrup. The labyrinth and all the connections of the membrane of the drum and ossicles, with the exception of the *ligamentum mallei superius*, were left undisturbed. As a sound-producing medium, organ-pipes were found to answer the purpose best. To connect these with the ear in such a way that the vibrations within the pipe might be conveyed with the least possible loss to the air contained in the external auditory canal, the open end of the pipe was closed with a thin board cover, and a glass tube 17 cm. long, and with a lumen of 14 mm., was firmly inserted into an opening in the centre of the board. The free end of the glass tube had been previously drawn out so as to present a lumen of 5 mm. This was made to fit tightly in the external ear by surrounding the end with sealing-wax. For light an ordinary kerosene lamp was used, the rays from which were concentrated by means of a convex lens on the spot to be observed. This had been previously dried with the end of a heated wire, and then sprinkled with powdered starch. These fine masses of starch, when examined with a low power of the microscope (24 diam.), appear-

ed as sharply defined luminous points, or, when set in rapid motion, as luminous lines. In the course of the experiments, however, it was ascertained that starch could be dispensed with, as the simple irregularity and moisture of the parts offered a sufficient number of luminous points for all purposes of observation.

Lengths of excursions on different parts of the ossicles.

The following measurements were made by means of an ocular micrometer. By turning the eye-piece round until the luminous lines ran exactly at right angles to the subdivisions of the micrometer, their lengths could then be readily measured. As far as possible they were taken from the same positions, namely, from above, as seen in Fig. 1, and from the side, as seen in Fig. 2.

With an organ-pipe of 110 *vibrations.*

Number of Specimen.	Head of Hammer from above.	Body of Anvil from above.	Head of Stirrup from above.	Head of Stirrup from side.
1	0.07 mm.	0.04 mm.	0.03 mm.	Not observed.
2	0.09 mm.	0.04 mm.	Scarcely visible.	" "
3	0.03 mm.	0.03 mm.	0.03 mm.	" "
5	0.04 mm.	0.03 mm.	Scarcely visible.	Scarcely visible.
6	0.04 mm.	0.03 mm.	" "	" "
Average =	0.05 mm.	0.03 mm.	0.01 mm.	

With an organ-pipe of 220 *vibrations.*

Number of Specimen.	Head of Hammer from above.	Body of Anvil from above.	Head of Stirrup from above.	Head of Stirrup from side.
1	0.28 mm.	0.14 mm.	0.03 mm.	Not observed.
2	0.28 mm.	0.16 mm.	0.06 mm.	0.06 mm.

3	0.12 mm.	0.07 mm.	0.03 mm.	0.04 mm.
4	0.12 mm.	0.06 mm.	0.03 mm.	0.03 mm.
5	0.06 mm.	0.03 mm.	Scarcely visible.	Scarcely visible.
6	0.09 mm.	0.05 mm.	" "	0.03 mm.
7	0.24 mm.	0.12 mm.	0.03 mm.	Not observed.
Average =	0.17 mm.	0.09 mm.	0.025 mm.	0.03 mm.

With an organ-pipe of 400 *vibrations.*

Number of Specimen.	Head of Hammer from above.	Body of Anvil from above.	Head of Stirrup from above.	Head of Stirrup from side.
1	0.28 mm.	0.12 mm.	0.06 mm.	Not observed.
2	0.21 mm.	0.12 mm.	0.06 mm.	" "
3	0.21 mm.	0.12 mm.	0.06 mm.	0.07 mm.
4	0.19 mm.	0.09 mm.	0.03 mm.	0.04 mm.
6	0.21 mm.	0.09 mm.	0.03 mm.	0.03 mm.
7	0.21 mm.	0.12 mm.	0.04 mm.	0.04 mm.
8	0.09 mm.	0.06 mm.	0.04 mm.	Not observed.
9	0.31 mm.	0.24 mm.	0.12 mm.	0.31 mm.
10	0.31 mm.	0.16 mm.	0.03 mm.	Not observed.
11	0.31 mm.	0.16 mm.	0.01 mm.	" "
Average =	0.23 mm.	0.128 mm.	*0.048 mm.	0.09 mm.

With an organ-pipe of 600 *vibrations.*

Number of Specimen.	Head of Hammer from above.	Body of Anvil from above.	Head of Stirrup from above.	Head of Stirrup from side.
1	0.09 mm.	0.04 mm.	0.01 mm.	Not observed.
2	0.07 mm.	0.04 mm.	0.01 mm.	" "
3	0.07 mm.	0.04 mm.	0.03 mm.	" "
4	0.06 mm.	0.03 mm.	Scarcely visible.	" "
Average =	0.07 mm.	0.037 mm.	0.012 mm.	

* By compressing the air in the external auditory canal and measuring the displacement in a column of mercury connected with the superior semi-circular canal, Helmholtz estimated the length of an excursion of the base of the stir rup at 0.05 + mm.—*Mech. der Gehörknöchelchen, etc.*, 1869.)

Direction of luminous lines on different parts of the ossicles.

As observed from above, the luminous lines on the heads of the hammer and anvil appeared slightly divergent outwards (see Fig. 1). This divergence was found to be the same on all the specimens. As observed from the side, in a direction at right angles to the long axis of the hammer, they presented the following appearance:—On the hammer the luminous lines appeared to be arcs of circles whose common centre lay in the immediate neighborhood of the *Processus Folianus* (see Fig. 2). On two of the specimens it was noticed that the luminous lines, measured at the very end of the handle of the hammer, were 0.43 mm. and 0.38 mm., whilst those measured at the head were 0.31 mm.; in other words, that in these instances, at least, the axis of rotation did not pass through the middle of the ossicle, but somewhat above it. On the anvil the luminous lines followed the direction marked in Fig. 2. On the lower part of the long process they seemed to be nearly or quite vertical, but on approaching the body of the bone they became more oblique. Owing to the enclosed position of the anvil, it was not found practicable to obtain an observation from the side higher up than the one marked in Fig. 2. On four specimens the relative measurements

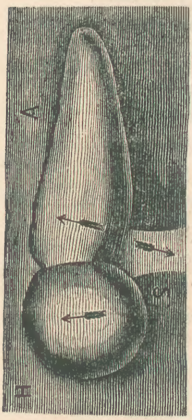


Fig. 1.

on the body (seen from above) and the long process (seen from the side) of the anvil were as follows:—

Number of Specimen.	Body.	Long Process.
8	*2	1½
9	8	10
10	5	2
11	5	3

They are of interest, as helping to indicate the position of the axis of rotation of this ossicle. In specimens No. 8, No. 10, and No. 11, the hammer and anvil were joined together in the ordinary manner as represented in Fig. 3, whilst in specimen No. 9 the anvil was more inclined inwards (see Fig. 4). In Fig. 3 (drawn from specimen No. 10) the luminous lines are arcs of circles whose common centre is at A. The top of the body of the anvil being twice as far from this centre as the end of its long process, its excursion is twice as great In Fig. 4 (drawn from specimen No. 9) the different lengths of excursion can only be explained by supposing the axis of rotation to be placed nearer the body of the ossicle (as at A′). As observed from

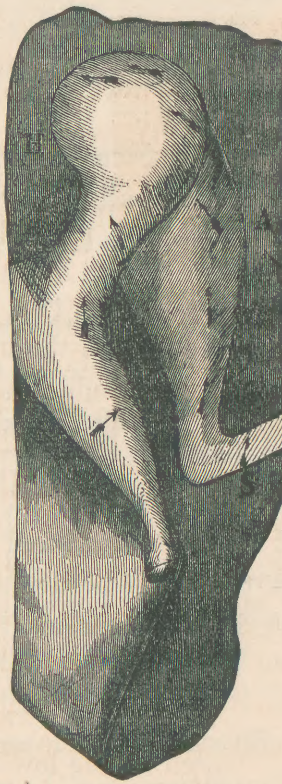


Fig 2.

* Number of micrometer subdivisions.

above, the luminous lines on the stirrup appeared in the majority of cases to be directed nearly, though not quite, at right angles to its base. In only two cases was it found possible to obtain a view of both arms of the stirrup at once. In one of these cases the luminous lines were directed at right angles to the base (see Fig. 5), while in the other they ran somewhat obliquely toward it. The inclination in all cases was toward the anterior extremity of the base (see Fig. 6).

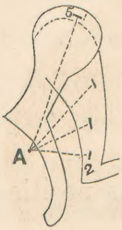


FIG. 3.

Viewed from the side, the luminous lines on the stirrup were in all instances directed obliquely upwards and inwards across the head and anterior arm (see Fig. 2).

In spec. No. 6 the upper and inner wall of the vestibule was carefully chiselled away, so as to present an inner view of the base of the stirrup. When it was put in vibration the luminous lines on the upper border of the base measured 0.03 mm., and were vertical, but on the lower border there was not sufficient motion to admit of measurement.

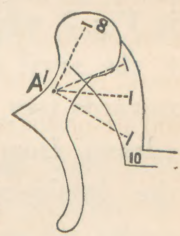


FIG. 4.

Fenestra Rotunda.

Enough of the lower wall of the drum was removed in specimen No. 1 to admit of a good view of the *membrana tympani secundaria.* The moment the organ-pipe was sounded the bright spot in the centre of the mem-

brane lengthened out into a distinct luminous line of 0.04 mm. On the head of the stirrup, as seen from above, the luminous lines measured only 0.03 mm. The superficial area of the *fenestra rotunda* being smaller than that of the base of the stirrup, a greater excursion might rightly be expected from the membrane of the former. In the present case the membrane was observed

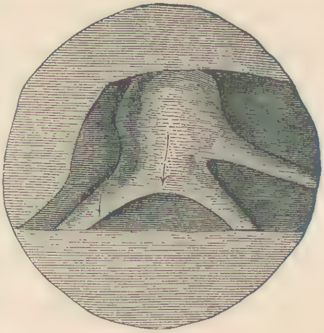


Fig. 5.

obliquely from the side and not directly in profile, so to speak; hence the measurement would represent only a portion of the true length of the excursion. The measurements on different parts of the ossicles, before and after breaking up the membrane, were the same.

The influence of the different ligaments.

Tendons of the *tensor tympani* and *stapedius*. The measurements immediately before and after the division of these tendons (considered as ligaments) were precisely the same, and no difference could be observed in the direction of the luminous lines on the stirrup after the division of the tendon of the *stapedius*.

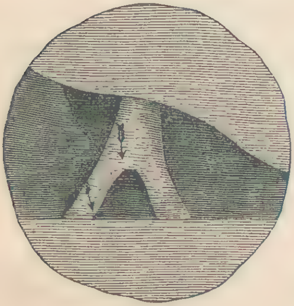


Fig. 6.

The modifications produced by attaching fine glass rods to the hammer and anvil.

A fine glass rod, of about the thickness of a fine bristle, and 5 cm. long, was glued in an upright position to the head of the hammer. Before doing this the measurements with an organ-pipe of 400 vibrations were:

Head of hammer = 0.31 mm.
Body of anvil = 0.16 mm.

Afterwards they were found to be:

Head of hammer = 0.12 mm.
Body of anvil = 0.06 mm.

Cutting off 1 cm. from the end of the rod, the measurements were:

Head of hammer = 0.16 mm.
Body of anvil = 0.09 mm.

Cutting off 2 cm. they were:

Head of hammer = 0.16 mm.
Body of anvil = 0.09 mm.

Cutting off 3 cm. they were:

Head of hammer = 0.18 mm.
Body of anvil = 0.10 mm.

Cutting off 4 cm. the measurements remained the same.

Leaving nothing but the small drop of glue, the measurements were:

Head of hammer = 0.24 mm.
Body of anvil = 0.12 mm.

After removing the glue from the head of the hammer and fastening a glass rod 5 cm. long and of the same thickness as the preceding to the body of the anvil,

the measurements with an organ-pipe of 400 vibrations were:

Head of hammer = 0.31 mm.
Body of anvil = 0.12 mm.

Cutting off 1 cm. they were:

Head of hammer = 0.31 mm.
Body of anvil = 0.13 mm.

Cutting off 2 cm. the measurements remained the same. Cutting off 3 cm. they were:

Head of hammer = 0.31 mm.
Body of anvil = 0.16 mm.

These experiments would show that the method of using glass rods to determine the character of the vibrations of the ossicles is not trustworthy. Even a drop of glue, the size of a pin's head, attached to the head of the hammer was sufficient to reduce its excursion 0.07 mm. On the anvil the disturbing influence of a weight or rod was much less than on the hammer.

Anatomical study of the manner of attachment of the Stirrup to the Fenestra Ovalis.

After having determined the direction in which the stirrup vibrates, the question presented itself, whether its base were not attached to the *fenestra ovalis* in a manner specially adapted to this mode of vibration. Works on anatomy give such meagre and conflicting information on this point that it was thought necessary to investigate it more thoroughly. The method employed

was suggested by Prof. Julius Arnold, under whose kind supervision the investigation was made.

The stirrup, together with the mass of bone immediately surrounding it, was first removed from the temporal bones of new-born children and adults as soon as possible after death, and in such a manner as to obtain this ossicle with all its attachments to the *fenestra ovalis* uninjured. These specimens were placed in three ounces of a 1% solution of chromic acid, the solution being renewed every fourth day after. At the end of a month a 2% solution was used. Two weeks later, two of the specimens were soft enough to be cut with the razor. The others remained a week longer in a 2% solution, to which three drops of concentrated hydrochloric acid had been added. From these solutions of chromic acid the specimens were transferred to alcohol, and, when sufficiently hardened, they were imbedded in paraffine. Fine sections were now made with the razor in both horizontal and vertical directions. In order to make the sections exactly parallel with the two axes of the base (the long or nearly horizontal, and the short or nearly vertical) the paraffine was carefully removed from the vestibular side of the stirrup, so as to expose only its base to view, whilst all the rest of the bone remained firmly imbedded in it. As some of the horizontal sections included the *musculus stapedius*, the anterior and posterior parts were easily determined. In the vertical sections the presence of the *tensor tympani* afforded the same assistance in locating the upper and lower parts.

In the study of these horizontal and vertical sections the base of the stirrup is found to be attached to the *fenestra ovalis* by a circular band of uniform strength throughout. Its fibres run in a convergent direction from the margin of the *fenestra* to the opposite margin of the base of the stirrup. In their course they cross each other at very acute angles. They are rich in oval nuclei, and are separated only by a slight quantity of an homogeneous, but dense intercellular substance. The periosteal covering of the bone in the immediate neighborhood of the *fenestra ovalis* is continuous with this circular band, or, in other words, the tympanic and vestibular layers of periosteum unite at the margin of the *fenestra*, then run together as one band as far as to the margin of the base of the stirrup, where they subdivide to take the base between their folds, and serve it in the capacity of periosteal covering.

On the outer side the band is covered everywhere with the mucous membrane of the drum, which was found here to be rich in blood-vessels of various sizes. In many of the horizontal and vertical sections, cross-sections were found of large arteries at the very edge of the *fenestra*, or even directly in front of the band. These sent off smaller branches that pierced the band in various directions.

On the inner side the band is also covered with an epithelial layer, which is, however, much thinner than the outer one.

In adults the bone forming the *fenestra ovalis* differs

in nowise from ordinary bony tissue, except that at the periphery, immediately beneath the periosteum, there is always found a thin layer of cartilage-like tissue, consisting of ovoidal and spindle-shaped cells and an homogeneous intercellular substance (periosteal cartilage). The same tissue is also found at the periphery of the bone in children, and moreover, in the very substance of the bone small cartilaginous islands are often seen.

The base of the stirrup is likewise formed of true bone, at the periphery of which there is found a thin layer of periosteal cartilage immediately beneath the periosteum, and intimately united with it. In adults the base was found to be thicker at the two ends than in the centre; the two ends were, however, very nearly alike in thickness. In children the posterior end was found to be thick and quadrangular, whilst the anterior was narrow and rounded (see accompanying plate). The layer of cartilage beneath the vestibular periosteum was found, moreover, to be much thicker than in the adult.

It is necessary to state here that unless the sections are either parallel or at right angles to the long axis of the base, they will totally misrepresent the true relations of the parts. For instance, among a number of vertical sections cut from the same specimen, I obtained three entirely different views: one where the lower border appeared somewhat flattened, whilst the upper was smaller and more pointed; a second, where the reverse was found to be the case; and a third, where both ends appeared alike. The breadth of the circular band varied

also, according to the direction in which the section was made.

To state briefly the results of this anatomical study: (1) The stirrup is attached to the *fenestra ovalis* by means of a circular band composed of elastic tissue; (2) The fibres of this band run from the margin of the *fenestra* to the base of the stirrup in a convergent direction; (3) The band is formed of the layers of periosteum covering the bone in the immediate neighborhood of the fenestra, and on reaching the base of the stirrup it again resumes its function of periosteum; (4) The band is everywhere of equal breadth.

From the preceding experiments two conclusions are arrived at: (1) That the bones of the ear vibrate as a whole; and (2) That with each vibration there is a corresponding displacement of the fluid of the labyrinth.* This is precisely the doctrine held by Weber twenty years ago. It also appeared that with each wave of sound the membrane of the drum is driven inwards a certain distance and then returns to its original position, so that the end of the handle of the hammer, which is imbedded in the substance of the membrane of the

* Politzer first proved experimentally that the ossicles vibrate as a whole (Archiv für Ohrenheilkunde, 1864). The chief question of dispute had been concerning the movement of the fluid of the labyrinth as a whole. Politzer and Helmholtz sided with Weber, whilst Henke and Schmiedekam held the contrary view.

drum, makes an excursion to and fro of equal length, and the length of such an excursion may amount to 0.43 mm. without any appreciable injury to the parts. But if one places the glass tube of the organ-pipe in his own ear the shock produced on the membrane of the drum is felt to be too painful to be borne for any length of time, so that the ordinary excursion of the membrane of the drum during life would seem to be much less than this measurement. The axis of rotation of the hammer lies nearly midway between its two extremities, so that when the end of the handle is driven inwards the head makes an equal excursion outwards. The particles forming the upper part of the head of the hammer move very nearly horizontally outwards, whilst those near the lower margin of the *malleo-incudal* joint move upwards as much as outwards. Helmholtz has shown that the hammer and anvil are united by a joint which in principle resembles that used in watch-keys, where the head of the key can be made to rotate in one direction without carrying the body with it, whilst in the opposite direction the body must necessarily follow. The lower tooth of the incudal half of the joint fits into a depression on the inner side of the hammer, just where the particles forming that part vibrate in an upward and outward direction. From an observation of the luminous lines on different parts of the anvil it was found that in fact such an upward and outward motion is communicated to this ossicle.

But in addition to this motion the body of the anvil

is thrown slightly backwards, or, in other words, the end of its long process is thrown forwards, as if the axis of rotation ran from the end of the shorter process of the anvil forwards, downwards, and outwards through the *processus brevis* of the hammer.

The head of the stirrup being joined to the end of the long process of the anvil by a fully formed capsular joint, it is obliged to follow to a great extent the direction taken by the end of the long process of the anvil, namely, upwards, slightly inwards, and forwards. As a result of this, the upper and anterior border of the base of the stirrup is driven farther into the vestibule than the lower and posterior border; * in other words, its axis of rotation runs either through the lower border of the margin of the *fenestra ovalis*, or a little below and parallel to it. Hence a displacement of the entire mass of the fluid of the labyrinth takes place, and in no other manner can the vibrations observed on the *membrana tympani secundaria* be explained.

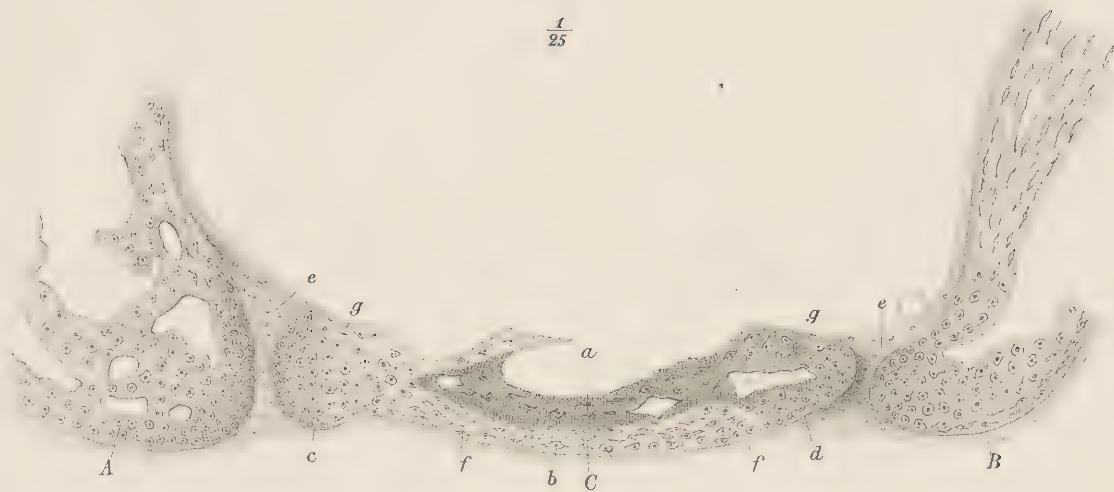
The average measurements show that an impulse given to the centre of the drum is communicated from ossicle to ossicle with a loss in the following ratio:—

Hammer = 4
Anvil = 2
Stirrup = 1

In two cases (see first table of measurements) where the

* By a somewhat different method of investigation Helmholtz determined the axis of rotation of the stirrup. The above result confirms his description in its essential points.

membrane of the drum was caused to vibrate feebly, scarcely any loss took place in the transmission of the impulse from the hammer to the stirrup. Taking into consideration, moreover, that all these measurements may be looked upon as representing rather the maximal than the ordinary excursions of the ossicles, it may well be doubted whether during life the loss in transmission be not much smaller than that given above



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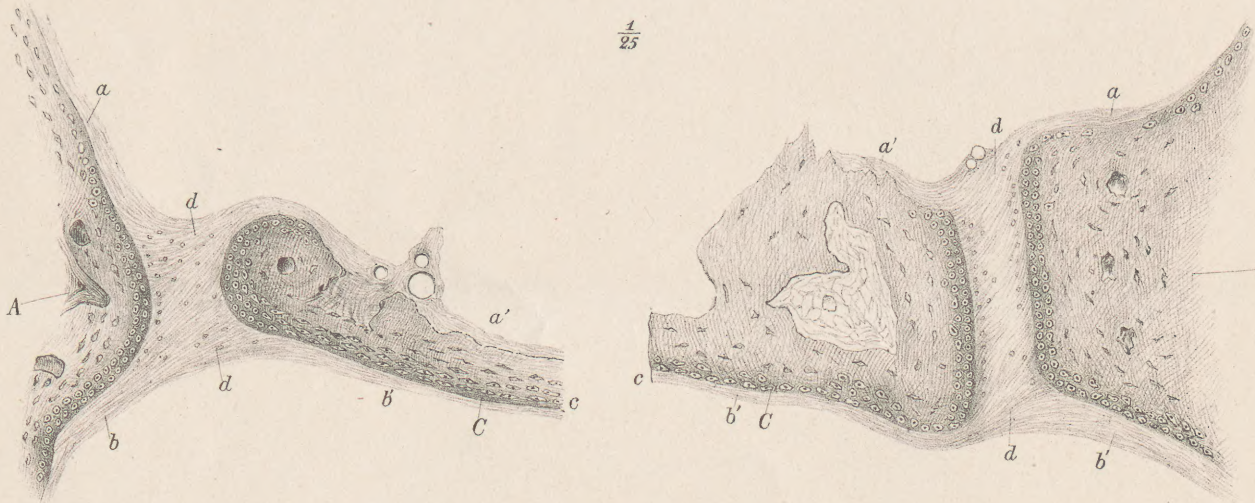

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